Demonstration of Lunar Ice Miner System Components

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Introduction: Mining volatiles on the moon's permanent shadow region forms the basis for lunar In-Situ Resource Utilization (ISRU). Volatiles trapped in the lunar regolith can be extracted and separated by a thermally driven sublimation process using a heat source. Currently, the major focus on ISRU is aimed at water/ice mining as it is important for human habitat survival and to produce of fuels like LO2/ LH2. The volatile mining operation can be categorized into extraction and collection.

To enable water/ice extraction, drill/auger technologies like PVEX drills [1] are prominently being developed. Under this work, a structurally enhanced, thermal corer based on the PVEX drill is being developed. The thermal corer is a minichannel embedded drill and utilizes waste heat from an onboard power source through a mechanically pumped fluid loop. As the heat transfer fluid circulates through the thermal corer, the water/ice sublimates from the icy-regolith soil and escapes as vapor. The ice-extraction performance achieved by the prototype thermal corer is discussed below.

The sublimated vapor is usually collected in the icy state in a cold trap tank, which is maintained below freezing point. The latent heat during the vapor-ice transition is rejected to the deep cold space. In the ongoing program, a Variable Conductance Heat Pipe (VCHP) integrated cold trap tank is developed for effective volatile collection by controlling surface temperature and heat transfer and spreading the ice-deposition area. This thermal control can be achieved by modulating the Non-Condensable Gas (NCG) concentration in the heat pipe which results in varying thermal resistance [2]. Further construction details and the operational mechanism of the VCHP cold trap tank being fabricated and tested are discussed below.

Thermal Corer for ice extraction: A prototype thermal corer of 5 cm ID and 17.3 cm long was fabricated by 3D printing with stainless steel (SS316). The schematic of the thermal corer profile can be seen in [3]. The HTF enters through the top manifold, which splits into four parallel minichannels. The minichannels spiral downwards with increasing channel size and eventually merge at the bottom of the thermal corer. The fluid loop is then drawn through the annular space along the thermal corer closer to the outside wall.

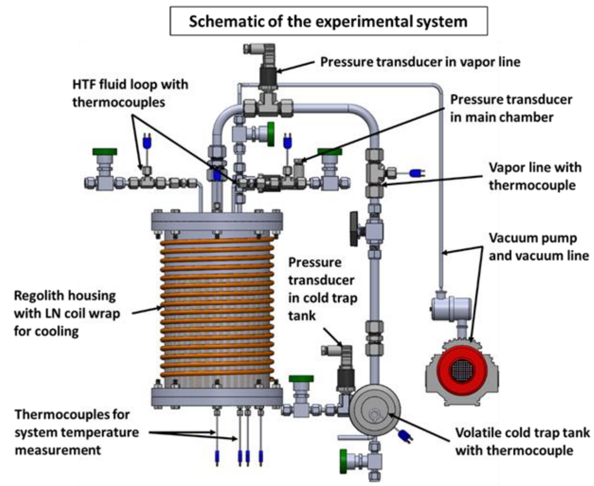

Figure 1. Schematic of ice-extraction test setup with thermal corer

To characterize the ice-extraction performance of the prototype thermal corer, a benchtop experimental system was fabricated. The schematic of the test setup is shown in Figure 1. The setup consists of regolith chamber. The regolith chamber is pre-packed with wet regolith with 5% wt water concentration. The regolith simulant material was LHS-Highlands 1 [4]. The thermal corer is then inserted into the regolith chamber. The regolith housing is connected to a proxy cold trap tank consisting of LN coils for ice-deposition. Thermocouples and pressure transducers are placed at various locations of interest to monitor system conditions during ice-extraction experiments. The experimental procedure is as follows: the system is cooled at a low temperature of about -20 to -30 °C and vacuumed to around 0.007 Torr by a turbo pump. HTF (Ethylene glycol) at constant temperature was circulated through the thermal corer for ice-extraction.

Figure 2. shows ice-deposition profile on the proxy cold trap tank when HTF circulation temperature was 75 °C. The corresponding temperature and pressure profile will be presented at the conference. It was observed that the ice deposition rate was the highest during the first half of the experiments (first 30 minutes). The ice-deposition rate then decreases with time. This was attributed to depleting ice-mass fraction in the captured regolith which lowers heat diffusion through the drying regolith, increasing pressure in the cold trap tank whose internal volume is only ~ 110 cc.

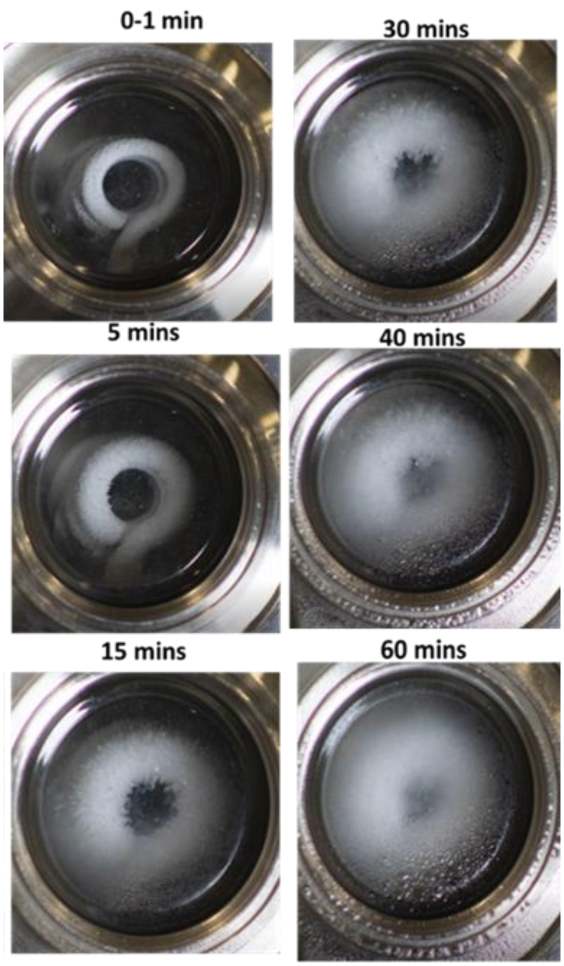

Figure 2. Ice-deposition on proxy cold trap tank with LN coils

Currently, tests are being performed to determine the ice-extraction performance of the thermal corer with a larger cold trap tank (internal volume 19X larger). The rate of increase in tank pressure in a larger tank will be significantly lower and this will result in enhanced ice-extraction performance.

VCHP cold trap tank: To facilitate ice collection a VCHP cold trap tank is being developed. VCHPs modulate the thermal environment in the tank to effectively spread ice in the tank and keep the ice-deposition surface relatively fresh for incoming vapor in subsequent ice-extraction cycles. This tank operates in two modes: ice-collection mode, and ice-removal mode. During ice collection, the sublimated vapor deposits as ice on the heat pipe surface, and the latent heat of ice is carried by the heat pipe and rejected to space through the radiator panels. During ice-removal mode, the NCG blocks the heat pipe access to the radiator panel. The ice layer on the heat pipe surface is melted during this time. The melted ice spreads at the bottom of the tank and the heat pipe surface is fresh for incoming vapor in subsequent ice-extraction cycles.

The schematic of the VCHP cold trap tank is shown in Figure 3. A comprehensive heat pipe design analysis was performed to determine suitable heat pipe geometry and working fluids. While, the analysis showed one heat pipe is sufficient for heat rejection, ten heat pipes were chosen to provide more surface area for ice deposition. Acetone was chosen as the working fluid based on the trade study. Detailed trade study calculations will be discussed at the conference.

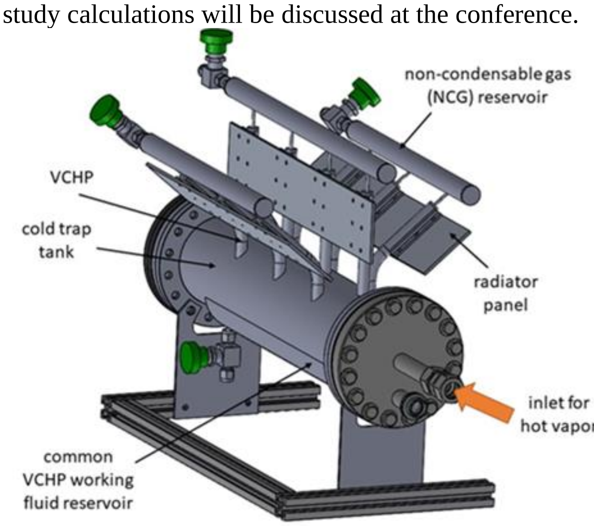

Figure 3. Schematic of VCHP cold trap tank

Currently, the VCHP cold trap tank is under fabrication. We anticipate performance demonstration results to be available for presentation at the conference.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] K. Zacny, K. Luczek, A. Paz, M. Hedlund, "Planetary Volatiles Extractor (PVEX) for In Situ Resouce Utilization (IRSU)", Earth & Space Conference, 2015. [2] https://www.1-act.com/products/variable-conductance-heat-pipes/. [3] K.L. Lee, Q. Truong, S.K. Hota, S. Rokkam, K. Zacny, "Waste Heat-Based Thermal Corer for Lunar Ice Extraction", 51st International Conference on Environmental Systems, St. Paul, MN, USA. 2022. [4] https://exolithsimulants.com/collections/regolith-simulants/products/lhs-1-lunar-highlands-simulant?variant=34875735277726